Renewable and Sustainable Energy Reviews 15 (2011) 993–1002

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A contribution in the actualization of wind map of Algeria

Farouk Chellali[a,c,*], Adballah Khellaf[b], Adel Belouchrani[c], Abdelmadjid Recioui[d]

[a] Unit of Applied Research in Renewable Energy, B.P. 88 Gaarat Taam, Z I, 47000 Ghardaia, Algeria
[b] Center of Development of Renewable Energies, Algiers, Algeria
[c] Electrical Engineering Departments, Ecole Nationale Polytechnique, EL Harrach, Algiers, Algeria
[d] Electrical Engineering Department, University of Boumerdes, Algeria

ARTICLE INFO

Article history:
Received 7 July 2010
Accepted 10 November 2010

Keywords:
Wind map
Time–frequency analysis
Weibull distribution
Wind speed
Techno-economical study
Hassi-R'mel
Algeria

ABSTRACT

In the following work, we propose an assessment of wind potential in Algeria. The purpose of this study is twofold. First, to draw the attention to the important wind potential in the region of Hassi-R'mel $\bar{v} \approx 6$ m/s. In the previous maps, the wind potential in this region has been underestimated due the fact that it is located between two less windy regions. Second, the actualization of the wind map of Algeria using very recent data stretching from February 2004 to December 2009. This paper is structured in three main parts. First, a stochastic and the cyclic study of the wind behaviors in the site of Hassi-R'mel are proposed. The stochastic study is carried out by fitting the wind speed data to Weibull distribution while the cyclic study is carried out via the use of time–frequency analysis. We have used the time–frequency analyses instead of the traditional Fourier analysis due its ability to follow the spectrum variation with respect to time. As results, it has been found that spectrum wind process enfold many limited interval oscillations. In the second part, we propose to contribute to the actualisation of the wind map in Algeria. In this part, we have considered also the topographical aspect of Algeria. Such consideration is very helpful for understanding the wind potential reparation over the country. Finally, a techno-economical study of a stand along hybrid system (wind/diesel) in the site of Hassi-R'mel is considered. Via this study, it has been found that been found that the site of Hassi-R'mel is very adequate for wind energy conversion systems.

Contents

Wind plays a primordial role in several domains such as wind energy conversion, transport, agriculture and fight against desertification. Hence, the knowledge of wind speed characteristics is of a great importance. Wind can be studied from the stochastic as well as the cyclic point of view. However, for better understanding

* Corresponding author at: Unit of Applied Research in Renewable Energy, B.P. 88 Gaarat Taam, Z I, 47000 Ghardaia, Algeria.
E-mail address: farouk.chellali@enp.edu.dz (F. Chellali).

1364-0321/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2010.11.025

of such phenomena, it is essential to incorporate other factors and sources that interact with it such as the topography and the urban environment.

In this work, we propose to carry out a stochastic as well as cyclic study of wind behaviors for the site of Hassi R'mel (32.9N°, 3.3E°), Algeria. The reason for choosing the site of Hassi-R'mel for study is that the recent measurements (From February 2004 to December 2009) have indicated that the region is characterized by an important wind potential with an annual wind average $\bar{v} \approx 6$ m/s. In the previous studies, the potential in this region has been underestimated due to the fact that it is located between two regions less windy. As a second objective of this paper, we propose to contribute to the actualization of the wind map of Algeria by inserting data of Hassi-R'mel. A comparison between the obtained wind map and the previous maps will be done to examine the influence of considering data of Hassi-R'mel on the overall wind map of Algeria. Finally, and to draw the attention to the important wind potential in the site of Hassi R'mel, a techno-economical study of hybrid stand alone system is considered.

In the field of wind potential in Algeria, earlier works dates back to 1984 among we can distinguish three approaches. The first is the establishment of atlases and maps of wind Algeria. In this framework, we can cite the work of Said and Ibrahim [1], followed by the works of Bensaid in 1985 [2] then comes Hammouche, in 1990 [3] and finally Kasbadji Merzouk in 2000 [4]. The second approach is the wind potential assessment and design of systems for converting wind energy. In this regard, one may cite studies of Himri et al. in the assessment of wind potential in the South and South-West of Algeria [5–7]. The work of Koussa et al. for Adrar region [8] and the work of Helal et al. for the region of Beni-Saf [9]. The third approach is the study of wind behavior. In this context, we can cite the work of Youcef Ettoumi et al. [10] who have proposed to model of wind speed by Markov process. Kasbadji has defended her doctoral thesis that has as subject the vertical modeling wind profile in Algeria [11]. Chellali et al. have carried out a spectral study of the wind speed using time–frequency analysis [12,13].

1. Stochastic and cyclic behavior of wind speed in Hassi R'mel

In this section, we propose to carry out a stochastic as well as a cyclic study of the wind speed behavior in the site of Hassi-R'mel. The stochastic study is done by fitting the density probability of wind speed to the Weibull distribution. However, the cyclic study is realized out by applying time–frequency analysis. The idea behind the use of time–frequency analysis is to study the variation of the spectral content of wind with respect to time. In fact, it has been shown in [12,13] that the use of such technique is helpful in understanding the cyclic behavior of wind speed in given region. In [12], it has been shown that the spectral content is seriously influenced by the topological factor. In addition to the cyclic study of wind, we propose also in this section to investigate the relationship between the cyclical behavior of wind and that of the atmospheric pressure. A similar analysis has been carried out for the site of Adrar in Algeria by Chellali et al. [13]. The authors in [13] have applied the wavelet coherence to study the correlation between wind speed and temperature. It has been found in that those two meteorological phenomena show a significant coherence for certain time intervals and frequency bounds.

1.1. ***Weibull distribution***

According to Carta et al. [14], the Weibull distribution is the most used in the literature related to wind speed fitting and it is practically the only recommended distribution in books on wind energy such as [15–18].

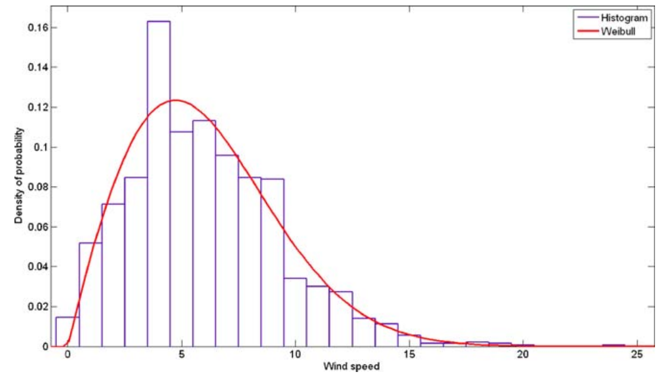


Fig. 1. Histogram of wind speed compared to Weibull distribution for the site of Hassi R'mel (c = 6.83, k = 1.95).

The Weibull distribution with two parameters is given by the following equation [18]:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

where c is the scale parameter and k is the shape parameter. The scale parameter has the same unit as the wind speed (m/s, miles/hour or knout). However, the shape parameter k is dimensionless. In the most of the meteorological conditions this shape parameter varies generally between 1.5 and 3 [19].

The estimation of Weibull parameters can be done via several methods such as the method of moments and the method of the maximum likelihood. According to Carta et al. [14], the maximum likelihood estimators $\hat{c}_L$ and $\hat{k}_L$ give the best estimation of the Weibull parameters. $\hat{c}_L$ and $\hat{k}_L$ are given as [18]:

$$\hat{k}_L = N\left[\frac{\sum_{i=1}^{N} v_i^k \ln(v_i)}{\sum^{N} v^k} - \sum_{i=1}^{N} \ln(v_i)\right]^{-1} \tag{2}$$

And

$$\hat{c}_L = \left[\frac{1}{N}\sum_{i=1}^{N} v_i^k\right]^{1/k} \tag{3}$$

Eq. (2) is non-linear equation that should be solved iteratively. Once the optimal $\hat{k}_L$ is found, it can be replaced in (3) to obtain $\hat{c}_L$.

The histogram in Fig. 1 is evaluated using daily average of wind speed during 6 years (from february 2004 to december 2009). The maximun daily averge of wind speed is $v_{\max} = 25$ m/s. Such results means that the site undergo to heavy wind speeds since we are speaking here about daily averages (mean of all the day).

In Fig. 4, we present also the estimated Weibull distribution. Fig. 4 indicates that the wind speed data in the site of Hassi R'mel satisfy the stochastic properties of the wind speed; the histogram fits Weibull distribution with c = 6.83 and k = 1.95 as parameters. However, it is important to mention that those values are obtained under the hypothesis that the process of wind is ergodic. This hypothesis allows considering that the temporal moments and the stochastic moments are equal.

1.2. Time–frequency analysis

Earlier studies on the cyclical behavior of wind speed dates back to 1956 when Vender Hoven has evaluated the power spectrum of the wind speed [20]. As results, it has been found that wind in New-York region is characterized by two types of periodicities. The first type is attributed to turbulences and it occurs at periods of 5 min. The second type of oscillations is synoptic oscillation. It occurs at

periods between 4 and 9 days and it is attributed to the passage of meteorological systems over the regions. After that, several similar works have been carried out to studies the cyclical behavior of wind over the world. A spectral study of the power density of wind speed on Palmyra Island has been considered by Hwang [21]. It has been found that the distribution of eddy kinetic energy in the medium and high frequency range in the tropics was quite similar to that at the middle latitudes. Militello and Kraus [22] have proposed to formulate the wind speed power spectrum in Taiwan using random vibration theory and statistical regression analysis. In addition to the study of the spectral behavior of the wind speed for six stations in Taiwan, Shih [23] have evaluated the cross-spectral density function.

Recently, the Wavelet transform has been used in the field of wind speed analysis as a time–frequency approach. Traditional Fourier analysis can be used to detect oscillations in given signal. However, it is not satisfactory in case of non-stationary. In case where a signal has a periodic component that appears only in limited intervals, Fourier analysis is completely enable to follow the spectrum variations with respect to time. In case of wind, it has been shown in [12] that the spectrum of wind speed in Algeria is time variable and it is seriously influenced by the topographical factor.

In this section, we propose to carry out a time frequency analysis on wind speed as well as on atmospheric pressure. It is known that those phenomena are widely correlated. Hence, we proposed to evaluate a coherency analysis to investigate such aspect.

1.2.1. Wavelet transform

Wavelet transform introduced by Morlet at the beginning of the 1980s has originally been used to analyze seismic signals. It is defined as [13]:

$$W(s,n) = \sqrt{\frac{1}{s}} \sum_{n'=0}^{N} x_{n'} \psi_0{}^* \left[(n'-n) \frac{1}{s} \right] \tag{4}$$

where s is the scale factor, n is the translation parameter and ψ_0 is the mother function that should satisfy the following wavelet admissibility condition

$$\int_{-\infty}^{\infty} \frac{|\psi_0(\omega)|^2}{|\omega|^2} d\omega < \infty \tag{5}$$

where $\psi_0(\omega)$ is the Fourier transform of $\psi_0(n')$.

Many wavelet mother functions have been proposed. In the present study, we have used the Morlet function because of its ability to reflect the gradual changes in the climatic records. The Morlet function is a modulated Gaussian function and it is given by:

$$\psi_0(\eta) = \pi^{-1/4} e^{j\omega_0 \eta} e^{-\eta^2/2} \tag{6}$$

where $\pi^{1/4}$ is the standardisation term and $\omega_0 = s\omega$ is a nondimensional frequency and s is the wavelet scale. In the present work, in order to satisfy the admissibility condition, the ω_0 value is taken to be 6. More details are given elsewhere [24]. It should be noted that in wavelet analysis the wavelet scale is directly related to the oscillation period ($p = 1.06\,s$ in case of Morlet wavelet) and hence to the frequency oscillation.

The wavelet transform can be used to study the spectral behavior of a given time series. However, to investigate the relationships of two time series, one can compare their corresponding WT or use the cross wavelet transform (XWT) defined as:

$$W_n^{XY}(s,n) = W_n^X(s,n) \cdot (W_n^Y(s,n))^* \tag{7}$$

where $(W_n^Y(s,n))^*$ denote the complex conjugate of $W_n^Y(s,n)$.

1.2.2. Wavelet coherency

The XWT is a useful tool to study relationships between two time series. However, its interpretation must be done carefully by paying attention to the original time series. High common power in the XWT may be due to a high power in both of the time series or from an extreme high power in one time series. Furthermore, if the wavelet transforms of two time series present low power at some specific time and scale, the XWT is enable to reveal their relationships even if those time series co-vary. To overcome such weakness in XWT, Torrence et al. [25] have proposed the use of the wavelet coherence (WTC) rather than the XWT.

The wavelet coherence is defined as the square of the XWT over the individual power WT [25]:

$$R_n^2(s) = \frac{|S(s^{-1} W_n^{XY}(s))|^2}{S(s^{-1}|W_n^X|^2) S(s^{-1}|W_n^Y|^2)} \tag{8}$$

where $S(\cdot)$ is the smoothing operator which is essential in coherence analysis. Otherwise the ratio $R(s)$ would be equal to one (for more details see [13]).

Values derived using the WTC vary between 0 and 1. The closer the WTC is to 1 the more coherencies there is between the time series.

The delay between two time series at some specific time and scale can be obtained by evaluating the phase difference $\phi_n^{xy}(s)$ defined as [25]:

$$\phi_n^{xy}(s) = \tan^{-1} \left(\frac{\Im(S(s^- W_n^{xy}(s)))}{\Re(S(s^- W_n^{xy}(s)))} \right) \tag{9}$$

In Fig. 2, we present the daily averages of the atmospheric pressure and wind speed. Due to some gaps in measurement between January and May 2008. Our study is limited to period between February 2004 and December 2007.

For figures that present the Wavelet scalograms, we should mention that frequencies of oscillations f are presented in term of periods $p = 1/f$. Periods are depicted in the ordinates in days while the time is presented in the abscissa. The area under the thin line indicates the zone of influence where the amplitudes may be attenuated due to the zero padding used in the calculation of the scalograms (for more details see [25]).

Fig. 3 presents scalograms of pressure and wind speed. For the pressure scalogram, it has been found the dominant oscillations occur at periods from 3 to 32 days. Their life time vary from two weeks up to three month. It is interesting to note that those oscillations are significant only in periods of autumn and winter. Concerning the scalogram of wind speed, it has been found that periods of most significant oscillations are located between 3 and 14 days and they are characterized by short life time (one to three week). Similarly to pressure, the wind speed oscillations have been observed in autumn and winter. The observed oscillations are generally called synoptic oscillations and they are attributed to the passage of meteorological weather systems over a given region [12].

However, some long period's oscillations (between 64 and 128 days) have been observed in Springer 2006 and winter 2007. Those periods are known under the name of Madden and Julian oscillations [26].Yet, it is important to mention that all the obtained scalograms present a significant periodicity at the annual frequency.

In Fig. 4, we have presented the wavelet coherency between the atmospheric pressure and wind speed. It has been found that the two meteorological phenomena co-vary significantly. At synoptic band (periods between 3 and 16 days), it has been observed that wind and pressure co-vary especially in autumn and winter. The usefulness of the coherency analysis appears in the in periods where one or both of wavelet power spectra of wind and pres-

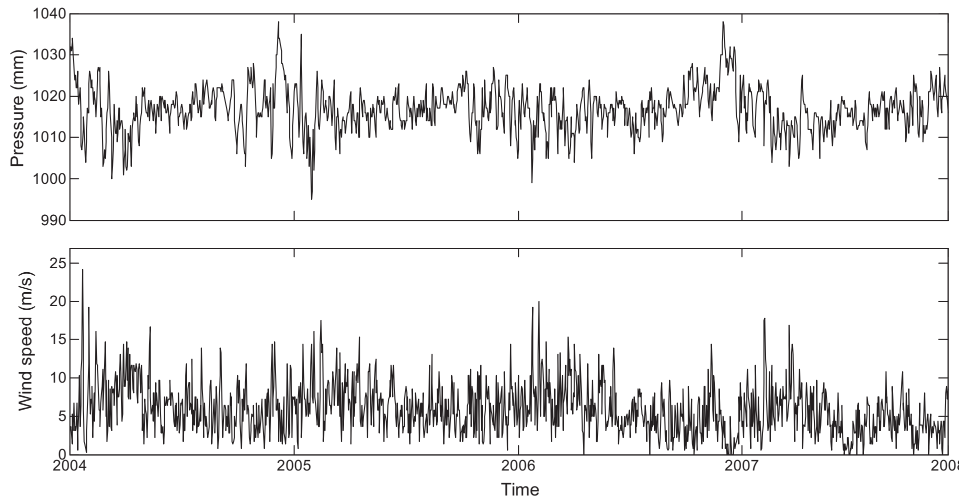


Fig. 2. Time series of daily atmospheric pressure and wind speed for the site of Hassi-R'mel, Algeria.

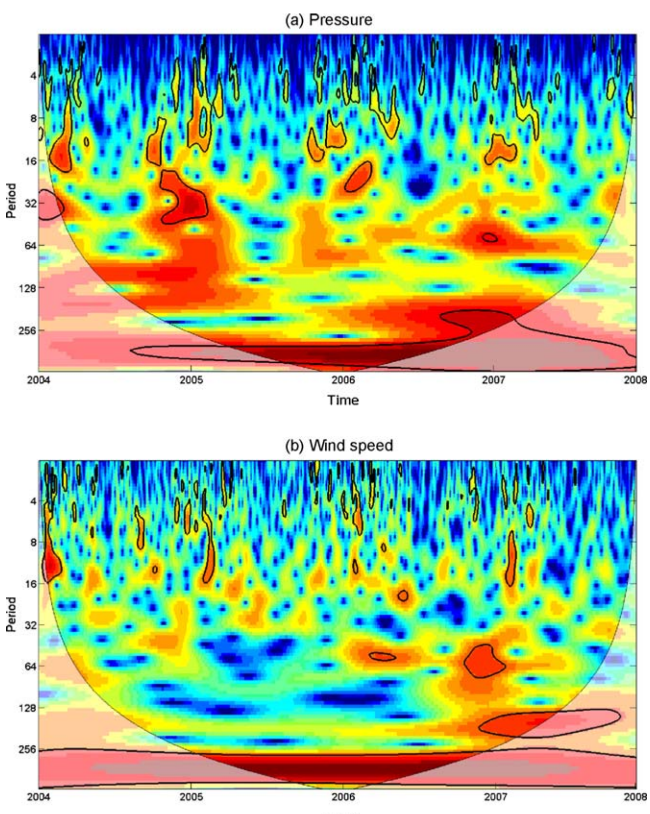


Fig. 3. Scalograms of atmospheric pressure and wind speed.

sure show low amplitudes. Long duration's coherencies have been observed in the band of 16–70 days (more than 0.8). Concerning the phase difference, arrows in Fig. 4 indicate that pressure is always loaded or in phase with wind. Physically this may be explained by the fact that the pressure belts are induced by wind.

2. Contribution to the actualization of wind map of Algeria

The estimation of wind energy available on a given site is probably the most important step when considering the establishment of a system of wind energy conversion. The study of the geographical distribution of wind resources available is very complex because it depends, in addition to climate, to several parameters such as topography and urban environment. Yearly maps of wind speed are important. However, the monthly maps of wind speed will allow the user to have better information on the evolution of this source of energy for a given region. Indeed, it is essential when installing systems for converting wind energy to know the periods for which these systems are more or less productive.

In this section, we briefly describe the distribution of wind resources in Algeria by the evaluation of the wind speed map. Earlier maps of wind speed in Algeria presented in [3,5,9] have been obtained by interpolation methods. Their results can be incorrect in the case where an intermediate zone considered to be windy between two less windy areas is not taken into account. Hence, we propose to contribute to the updating of the wind speed map of Algeria through the use of recent data (2004–2009) and also by adding data of the region of Hassi-R'mel. The potential in this region has been underestimated due to the fact that it is located between two less windy regions. The results are given in the form of maps and tables to allow easy reading and to have a general idea about the geographical distribution of wind resources.

2.1. Used data

This study is based on the average daily wind speed. We have used data measured at 10 m above ground level from 37 weather stations in the network of National Meteorological Office (ONM). The measurement period stretch from February 2004 to December 2009 (6 years). However, it is important to note that those measure-

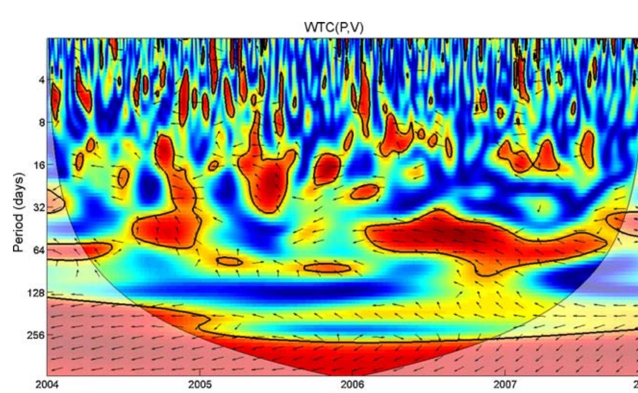


Fig. 4. Wavelet coherency between atmospheric pressure and wind speed.

ment stations are generally located either in airfields or in urban sites. This means that the potential may be greater elsewhere especially in isolated and remote sites. Algeria is located between the subtropical arid zone and the south Mediterranean coastal line. It is influenced by three main ascendant climates. First, the South Mediterranean climate characterized by wet winter and dry summer. Second, the dry subtropical climate with very cold winter and summer from warm to hot. Third, the Saharian climate for deserts found in low latitude between 18°N and 28°N. Those deserts coincide with the edge of the equatorial subtropical high pressure belt and trade winds.

2.2. *Wind map of Algeria*

The average monthly and annual wind speeds are presented in Table 1 which also includes the geographical coordinates and elevation above sea level for each site. This table will allow us to have an idea on evolution of the wind speed according to the months of the year.

Except for the region of Hassi-R'mel where it has been found that it has an important wind potential (4.8–8.1 m/s), the general appearance of the obtained maps are similar with the maps obtained in the previous studies (Fig. 5). Algeria is generally quite windy. 78% of its surface is characterized by velocities exceeding 3 m/s with about 40% of these speeds are above 5 m/s. Wind maps show that the highest wind speeds are distributed in the south while the north is generally less windy. It was found also that the southwestern region has a great potential with speeds exceeding 4 m/s for the site of Bechar, 5 m/s for the site of Tindouf and even above 6 m/s for the site of Adrar. The fact the southwestern region of the country has a significant wind potential can be attributed to two factors: the first is that it is located in an area of pressure difference (wind in the latitudes near 30°N). The second is that it is close to the Athletic Ocean (weather disturbances reaches the region with high intensity).

On the other hand, in southeastern part of the country, it has been found that the wind potential is relatively weaker with respect to the western part. The highest speeds of 4.5 m/s were observed for the region Inamenass. So for the Tamanrasset region, we observe that the wind potential is below 4 m/s. taking into account the topographical aspect, the decrease of wind potential in this region can be attributed to the mountains series of Tassili which distracts and prevents some weather disturbances to reach the region. This is well illustrated in Fig. 6 which shows the annual distribution of wind speed in Algeria projected onto the topographical map of Algeria.

Concerning the site of Hassi-R'mel, Table 1 indicates that it has a very significant wind potential ($\nu \approx 6$ m/s). This potential has been underestimated in the previous studies because this site is located between two less windy sites (Laghouat and Ghardaïa). From Fig. 6, this potential can be attributed to a corridor of air that crosses the region (tunnel effect).

Based on Table 1 and Fig. 7 that presents the monthly averages of wind speed in Algeria, we can see that the wind in Algeria obeys the same monthly rules. Thus, it becomes possible to classify months in term of average wind speed. We note that the months in spring (April, May, and June) are the windiest especially in internal zones. In spring, these regions are characterized by heavy dusty winds. Nevertheless, it has been noticed that in the southwest regions, Monthly velocities vary a little. Taking into account such results, this region is very favorable and adequate for the systems of wind energy conversion. As for the region of Hassi R'Mel, we note that the difference between the monthly averages is important; the windy months are undoubtedly those of April (ν = 8.1 m/s), May

Table 1
Monthly and annual averages of wind speed in different site in Algeria.

	Elévation	Latitude	Longitude	January	February	March	April	May	June	July	August	September	October	November	December	Yearly
Adrar	280	27.8	–0.2	6.2	6.4	6.5	6.5	6.9	6.1	6.7	6.2	6	5.8	5.9	5.8	6.3
Ain Sefra	1174	32.8	–0.6	4.6	5.1	5.1	5.4	5.2	4.9	4.3	4 2	4.1	4	4.2	4.9	4.7
Algiers	25	36.8	3.1	2.2	2.2	2.2	2.1	1.9	1.8	1.6	1.5	1.6	1.4	1.9	2.4	1.9
Annaba	4	36.8	7.8	2.5	2.4	2.5	2.2	2.1	2.2	2.4	2.3	2.3	1.8	2.4	2.5	2.3
Batna	822	35.2	6..3	2.9	3 1	3.6	3.2	2.7	3	3	3.1	3	2.7	2.6	3.3	3
Bechar	881	31.7	–2.3	3.2	3.2	4.1	4.6	5	4	4.1	4	3 7	2.8	2.9	3.1	3.7
Bejaia	2	36.7	5.1	3.7	3.4	2.9	2.8	2.5	2.4	2.4	2.3	2.7	3.2	3.6	4.1	3
Biskra	87	34.8	5.7	3.9	4.3	4.9	5.3	5.1	4.3	3.8	3.7	3 9	3.3	4	4.1	4.2
Bou-saada	461	35.3	4.2	5.5	5.1	6.3	5.1	4.3	3.2	2.5	2.6	2.8	3.1	4.7	5.5	4.2
Chlef	143	36.2	1.3	3 1	3.5	3.3	2.6	3	2.7	2.1	2.4	2.7	2.9	3	3.1	2.9
Constantine	694	36.3	6.6	4	3.3	3.5	2.7	2.5	2.1	1.8	2	2	2.1	2.8	3.4	2.7
Djanet	967	24.3	9.5	3	2.9	3.5	4.1	4	4.2	4.1	4.2	3.5	3.2	2.4	2.4	3.5
Djelfa	1144	34.7	3.2	3.2	5	5.2	5.6	4.7	5.1	4	4.2	4	3.9	3.6	3.5	4.3
El-Golea	397	30.6	2.9	2.8	3.8	4.3	4.2	4.7	3 9	3.3	3.2	3.7	3.5	2.6	3	3.6
Eloued	61	33.5	6.8	2.6	2.7	3.6	4	3.9	3.8	3.5	3.5	3	2.6	2.3	2.6	3.2
Chardaia	450	32.4	3.8	3.5	3.2	4.4	4.5	3.9	3.5	2.9	2.7	3	2.8	2.8	3.5	3.4
Chelma	4	36.5	7.7	2.4	2.3	2.5	2.2	2.1	2.2	2.4	2.3	2.3	1.8	2.4	2.5	2.3
Griss	90	35.2	0.2	2.7	2 3	2.3	2	2.1	1.7	1.5	2	1.9	1.9	2.6	2.7	2.1
H Messaoud	142	31.7	6.2	3.2	3.3	4.1	4.2	4.8	4.1	3.4	3.7	3.9	3.5	2.8	3.1	3.7
H R'mel	774	32.9	3.3	5.7	6.3	7.6	8.1	7.8	6.6	5.3	5.4	5 4	4.8	4.5	5.7	6.1
Illizi	558	26.5	8.4	3.7	3.7	4.1	4.1	4.5	4.9	4.6	4.6	4.3	3.9	3.7	3.4	4.1
Inamenass	562	28	9.6	3.9	4.5	5	5.2	6	5.7	4.6	4.8	4.7	4.4	3 .9	3.8	4.7
InSalah	293	27.2	2.5	5.3	4.9	5.5	5.1	5.6	5.3	5.6	5.3	4.9	4.6	4.7	4.3	5.1
Jijel	11	36.8	5.9	2.6	2.9	3.3	2.8	2.1	2.1	2.1	2	2.1	2.2	2.5	3.1	2.5
Laghouat	765	33.8	2.9	3.4	3.4	3.9	4.3	3.8	3.6	3	2.9	2.8	2.6	2.7	3.3	3.3
Oran	90	35.6	–0.6	2.7	2.8	3.2	3	3	2.9	2.6	2.3	2.3	2.1	2.4	2.7	2.7
Ouragla	142	31.9	5.4	3.1	3.3	4.3	4.2	4.9	4.7	4	4.1	4.3	3.5	2.8	2.8	3.8
Setif	1040	36.2	5 3	3.4	3.8	3.8	3.7	3.3	3 4	3.2	3.3	3.4	3	3.2	3.1	3.4
Tamanrasset	1378	22.8	5 4	3.4	2.9	2.9	2.9	3.1	3.2	3.3	3.2	3	2.9	2.5	2.6	3
Tebessa	811	35.4	8.1	3.2	3.2	3.5	3.1	2.9	2.5	2	2.1	2.3	2.4	2.9	3.3	2.8
Tiaret	989	35.3	1.5	3	4.1	3.8	3.2	3.5	3	2.6	2.8	2.9	2.9	3 6	4	3.3
Timimoun	312	29.2	0.3	5	5.6	5.3	5.9	6.1	4.8	4.9	4 .9	4.5	4.1	4.4	4	5
Tindouf	431	27.7	–8.1	4.6	5.4	5.3	7	7.3	7.3	5.6	6.2	6.7	4.7	4.3	4	5.7
Tlemcen	247	35	–1.5	3.7	3.2	3.3	2.3	2.1	1.8	1.5	1.6	1.4	2.4	3.1	3.9	2.5
Touggourt	85	33.1	6.1	2.9	3.1	3.9	4.1	4.2	3.7	3.4	3.7	3.2	2.9	2.5	2.9	3.4

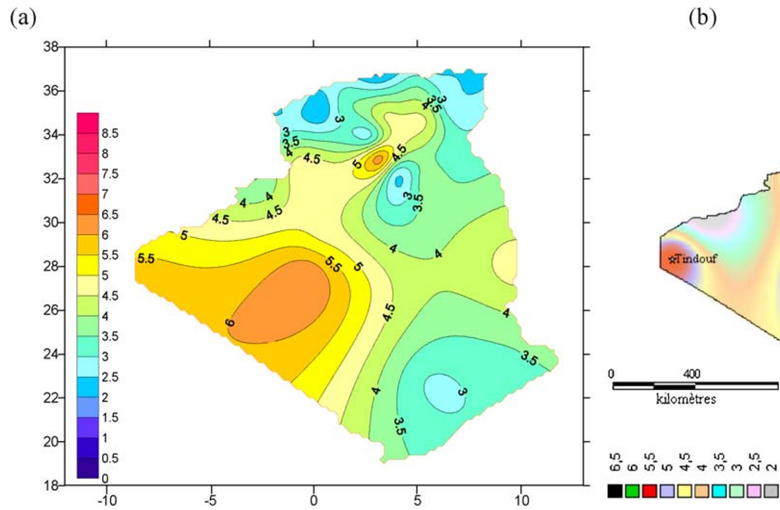


Fig. 5. Annual maps of wind speed in Algeria at 10 m high. (a) Map obtained form Table 1(b) Map obtained in Ref. [11].

(v = 7.9 m/s) and Mars (v = 7.6 m/s). As for the months of October and November, we note that the potential wind does not exceed 4.8 m/s. This can be considered as an inconvenient in the wind energy conversion field.

Finally, it is important the to mention that these studies were conducted as part of work for estimating the wind potential in Algeria. However, the number of sites is little and therefore these studies can be regarded as preliminary results. As this study shows for the case of Hassi-R'mel, a windy area has been neglected. Much work remains to be done because the weather stations of the National Office of Meteorology (ONM) located mainly at urban areas and airports are not sufficient to characterize the wind potential in Algeria. More over, the Algerian territory is vast (more than 2.4 millions km^2) and these stations are scattered with large distances especially in the south. To locate windy areas (especially remote and isolated areas), we encourage specialists to use ecological indicators and conduct investigations with people living in isolated areas especially cattle ranchers and truckers because the nature of their work depends heavily on the behavior of wind. Indeed it is thanks to the truckers signs we became interested is to the region of Hassi-R'mel.

N.B. in Arabic terminology, the name Hassi-R'mel means the source of sand. The nomads of the region have given this name to this region because it is always characterized by heavy sand storms.

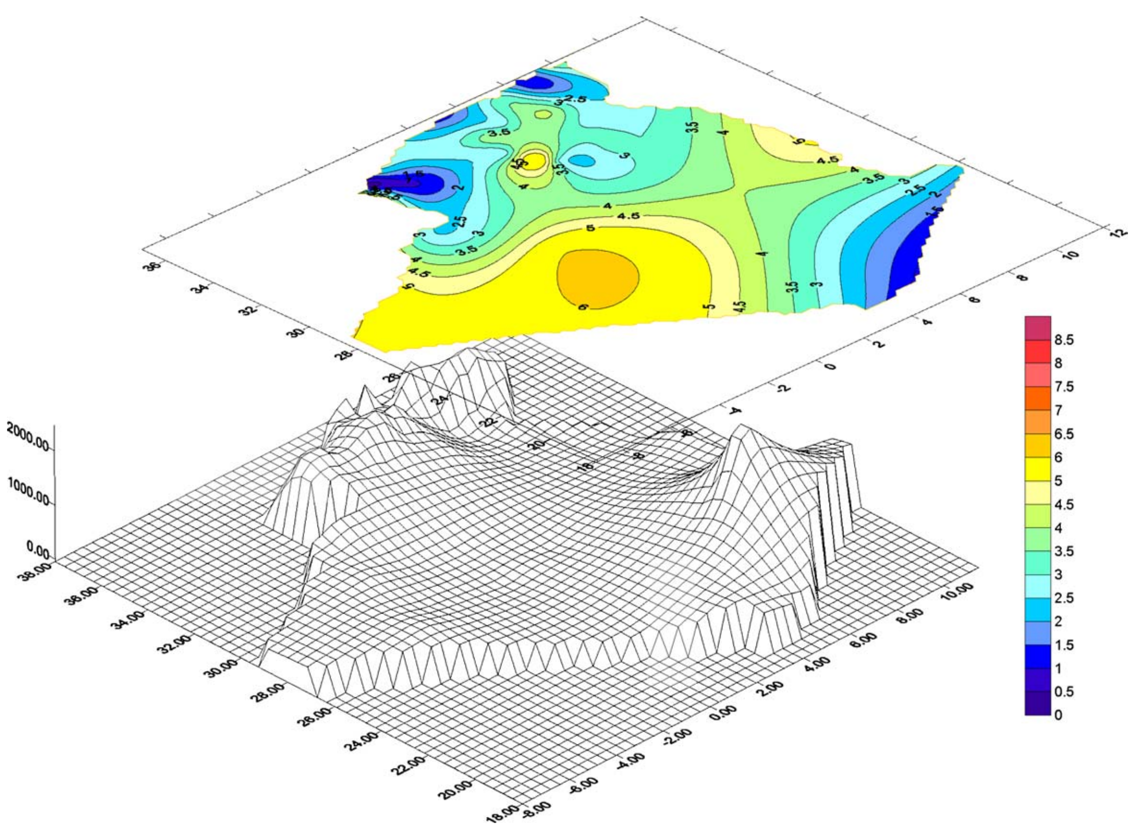


Fig. 6. Wind speed map projected on the topographical map of Algeria.

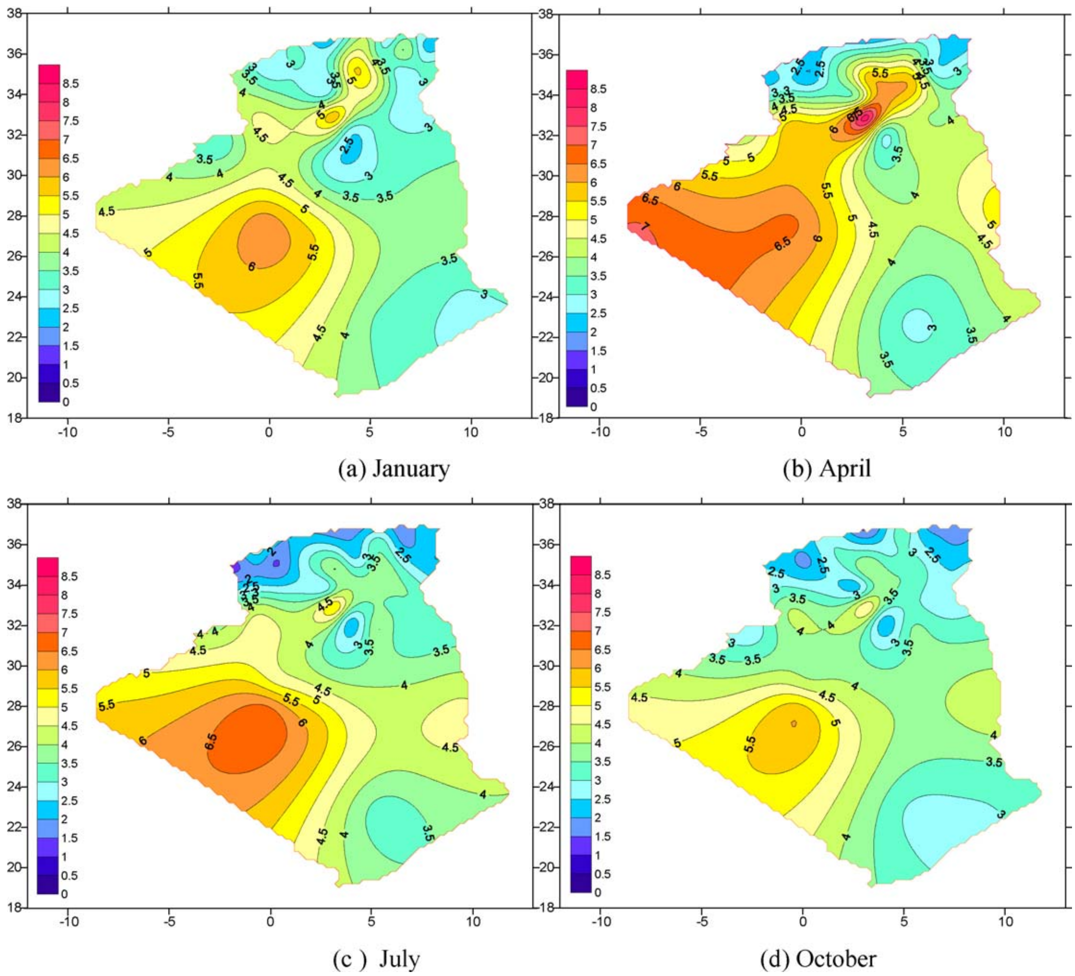


Fig. 7. Monthly maps of wind speed in Algeria (data from February 2004 to December 2009).

3. Application: stand along hybrid system

As mentioned above, several studies have been carried out in order to estimate the appropriate dimensions of stand-alone hybrid systems in Algeria. However, in all those above studies, only the South-Western part of the country has been taken into consideration. In this part, a system optimization in terms of technical and economic feasibility is proposed. The purpose of this part is to draw the attention to the enormous potential of wind energy in the region of Hassi-R'mel that can be exploited in collecting further energy than the solar type already installed. The proposed study is carried out using Homer Software.

HOMER software is a user-friendly micropower design tool that simulates and optimizes stand-alone and grid-connected power systems. Recently, it is has been used widely in the field of renewable energy such as the techno-economical studies of hybrid systems in Algeria [6], Saudi Arabic [27] and [28]. It can be used with any combination of wind turbines, PV arrays, run-of-river hydro power, biomass power, internal combustion engine generators, microturbines, batteries, and hydrogen storage, serving both electric and thermal loads. The advantage of the HOMER is that it can involve also all costs such as the initial capital and the maintenances costs including pollution penalties [29]. The simulation considers a one-year time-period using a minimum time-step of 1 min. It performs a sensitivity analysis which can help the

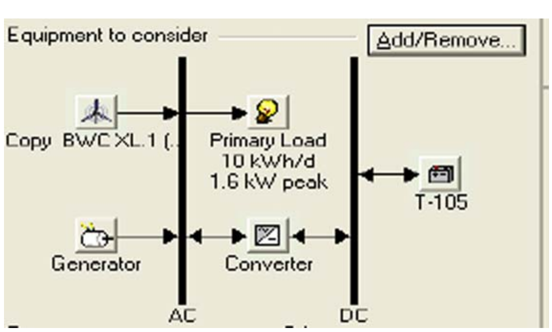


Fig. 8. The hybrid system considered for optimisation.

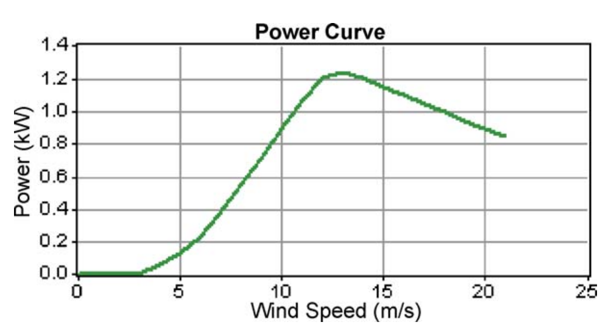


Fig. 9. Typical power curve for BWC XL1 wind turbine.

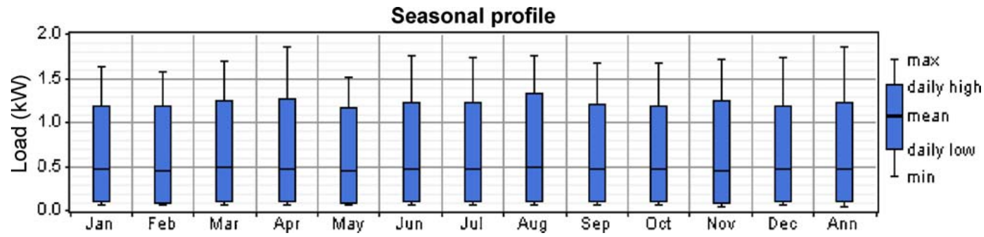


Fig. 10. The seasonal profile of the considered load.

analyst to do 'what-if' analyses and to investigate the effects of uncertainty or changes in input variables. The objective of the optimization simulation is to evaluate the economic and technical feasibility for a large number of technology options, while considering variations in technology costs and energy resource availability.

3.1. The considered system

The system under consideration for optimization is a stand alone wind/Gasoline generator hybrid system as shown in Fig. 8. The wind turbine is a modified version of the Bergey windpower BWC XL1 type which has a rated power of 1.24 kW AC. It has a lifetime of 20 years with a hub height of 25 m. The typical power curve of this turbine is shown in Fig. 9. The capital cost of this turbine is at 3900$ with the replacement assumed at the same price and the operation/maintenance costs at 100$/year. The number of turbine to be used can go up to 3 items. The Gasoline generator is a 2.6 kW with a capital cost of 900$ and a lifetime of 5000 operating hours. Again replacement is assumed to be at the same price with the operation/maintenance costs at 0.04$/h. The fuel price is taken to be constant (which is the case in Algeria) and is at 0.2$/Litter. To take into account any economic effects on the gasoline prices and to assess the effect of this parameters on the system choice, this price has been allowed to vary increasingly up to 0.6$/L. The system contains batteries of the type T-105 of the Trojan battery company. Their capital cost is at 220$ with the same replacement cost and operating/maintenance cost of 4$/year. The number of such a battery can be none or range from 13 to 16 items. For DC/AC or AC/DC conversion, up to 5 items of a 1 kW converter may be used. The capital cost of such a converter is fixed at 750$ at the same replacement price and no operating/maintenance costs. These have 15-year lifetime and 90% efficiency.

3.1.1. The load profile

The load demand considered is for home consumption profile. The seasonal profile is shown in Fig. 10. It shows a relatively constant power demand over all the year. The daily consumption is assumed to be follow the same profile over al the year and is shown in Fig. 11. It shows that the consumption is important in the daytime and negligible at night. It peaks at three points: at the early morning; at noon and at the beginning of the night as all the family

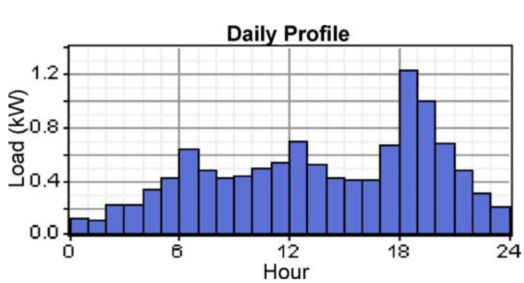
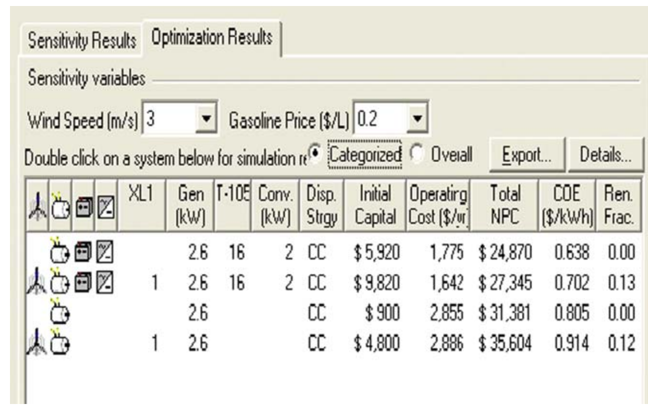


Fig. 11. The daily consumption of the considered load.



	XL1	Gen (kW)	T-105	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
		2.6	16	2	CC	$ 5,920	1,775	$ 24,870	0.638	0.00
	1	2.6	16	2	CC	$ 9,820	1,642	$ 27,345	0.702	0.13
		2.6			CC	$ 900	2,855	$ 31,381	0.805	0.00
	1	2.6			CC	$ 4,800	2,886	$ 35,604	0.914	0.12

Fig. 12. The optimisation results with the optimum systems ranked.

members are around. The annual average daily consumption is at 10 kW/day.

3.1.2. Other input data

Besides the specifications listed earlier, some other factors have been set as additional specifications and constraints so that the problem is complete. First, the project lifetime has been set out to be 25 years with an annual interest rate of 8%. To highlight the stand alone system importance, the cost of connecting to the nearest grid is set to be 10,000$/km while the price of purchasing a kWh is fixed at 0.1$/kWh. Emissions are not taken into account in the optimization procedure (Lows in Algeria do not consider penalties for CO_2 emission).

3.2. Optimization results

Once the earlier described specifications have been set into HOMER, it performs calculations to determine the best combination that technically and economically meets the requirements. The

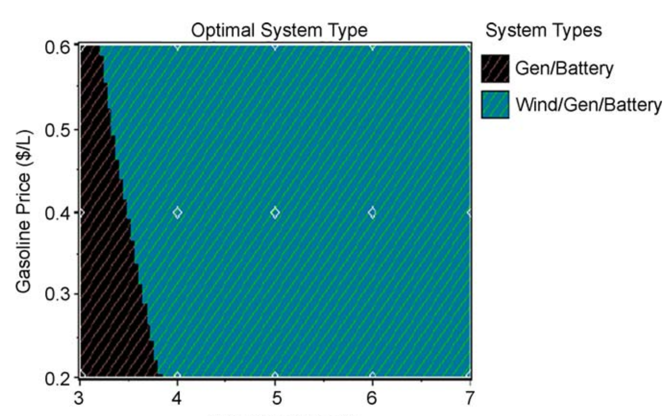


Fig. 13. Sensitivity analysis for wind speed and gasoline price parameters.

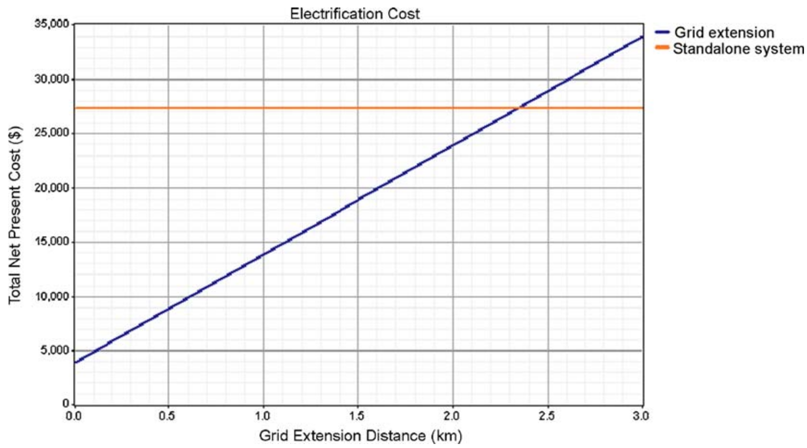


Fig. 14. A comparison between stand alone and grid connection alternatives.

Table 2
Comparison of polluant emissions for the optimum systems. (a) Diesel/battery system. (b) Wind/diesel/battery system.

Pollutant	Emissions (kg/yr)	Pollutant	Emissions (kg/yr)
Carbon dioxide	5856	Carbon dioxide	4929
Carbon monoxide	16.4	Carbon monoxide	13.8
Unburned hydrocarbons	1.82	Unburned hydrocarbons	1.53
Particulate matter	1.24	Particulate matter	1.04
Sulfur dioxide	12	Sulfur dioxide	10.1
Nitrogen onides	146	Nitrogen oxides	123
(a)		(b)	

results are shown in Fig. 12 where the optimal systems are ranked according to their technical and economic feasibility. The optimal system is found to be the gasoline generator combined with the battery bank followed by the combination wind turbine with the gasoline generator and battery bank. It should be noted that the first system overtook the wind based system because the speed considered a wind speed of 3 m/s as pointed out earlier which is a too underestimated value. In Addition to that, we should mention that the price of the gasoline is subsidized in Algeria (the real price is three times more). To better visualize the effects of both wind speed and gasoline price, a sensitivity analysis over the two parameters has been carried out and the results are depicted in Fig. 13.

The results point out that for the current price of gasoline of 0.2$/L, a speed of around 3.8 m/s is enough to favour the wind-based system and less speed values even favour this system for possible increase in prices.

This result is very important as it draws the attention that wind energy resources in the region are considerable especially as the true annual speed is 6.098 m/s. The amount of energy that can be drawn can serve as another source that can go hand in hand with the already existing awareness and care about the solar energy systems. HOMER produces the amounts of emissions of the wind-based system along with the amount of emissions produced by the rank 1 system which are summarized in Table 2. The results reveal that the involvement of wind turbine reduced the amount of emissions of the different components. Fig. 14 shows a comparison between which alternative best serves our needs either the stand alone system or the grid connection. The stand alone system is the best choice starting from a distance from the closest grid connection of 2.4 km which is the case for as any remote area.

4. Conclusion

Through this study, a contribution to the actualization of the wind map in Algeria has been carried out by adding data of the site of Hassi R'Mel. In the previous maps, this potential has been under estimated due the fact this region is located between two less windy regions (Laghouat and Ghardaia). It has been found that the site of Hassi R'mel is characterized by an important wind potential with an annual wind mean speed $v \approx 6$ m/s. In order to understand reason of wind repartition in Algeria, we have projected the wind map over the topographical map of Algeria. Decrease of wind potential in south-east part has been attributed to the mountainous series of Tassili (In Tamanrasset region). Those series prevent many metheorological perturbations to reach the east part. For the region of Hassi R'mel, the wind potential is attributed to this potential is attributed to a corridor of air that cross the region (tunneling). In the obtained maps we have used very recent data (2004–2009) and we have conduced that Springer is the windiest season. However, our maps are considered to be preliminary due to the fact number of used stations is little regarding the surface of Algeria (more than 2.4 millions km^2). Moreover, these stations are generally located on airfields or in urban centers and measurements are intended to aviation or climatology. These measuring conditions do not take into account certain requirements related to the environment (obstacles, topography) that may influence the representativeness of the measures.

It has been also found that the density of probability of wind in Hassi-R'mel obeys to Weibull distribution. However, for the study of cyclic behavior of wind in this site, we have used the time–frequency approach due to the fact that wind is not stationary process. The study has reveled that the presence of synoptic oscillations of periods between 3 and 16 days. Those oscillations are generally observed in autumn and winter and they are characterized by a short life time. Those oscillations are attributed to the passage of weather systems that cross the region in the hibernal season. The study of coherency between wind speeds and pressure have reveled a great coherency between the two phenomena especially at low frequencies.

In this work, an optimization of a hybrid stand alone wind based energy system has been considered. The optimization task has been carried using that powerful tool HOMER which successfully determined the best technical and economical system to adopt. The system considered, though simple in construction, has successfully demonstrated that wind energy is another option to adopt in Hassi R'mel which possesses a potential of wind energy besides solar energy that can be economically beneficial to Algeria. The calculations have shown that the wind-based energy system is the best in terms of economical, technical besides its environmentally friendly characteristics that give it an important role in the country's sustainable energy strategy.

References

[1] Said M, Ibrahim A. Energy in the Arab World. Energy 1984;9(3):217–38.

[2] Bensaid H. The algerian program on wind energy. Proceeding of WEAC. Oxford; 1985. p. 21–27.

[3] Hammouche R. Atlas Vent de l'Algérie/ONM. Office des Publications Universitaires (OPU), Alger; 1990.

[4] Kasbadji Merzouk N. Wind energy potential in Algeria. Renewable Energy 2000;21:553–62.

[5] Himri Y, Himri S, Boudghene A, Stambouli. Wind power resource in the south-western region of Algeria. Renewable and Sustainable Energy Reviews 2010;14:554–6.

[6] Himri Y, Boudghene Stamboulib A, Draouic B, Himrid S. Techno-economical study of hybrid power systemfor a remote village in Algeria. Energy 2008;33:1128–36.

[7] Himrib Y, Rehmana S, Draouic B, Himrid S. Wind power potential assessment for three locations in Algeria. Renewable and Sustainable Energy Reviews 2008;12:2495–504.

[8] Saheb-Koussa D, Haddadi M, Belhamel M. Economic and technical study of a hybrid system (wind–photovoltaic–gasoline) for rural electrification in Algeria. Applied Energy 2009;86:1024–30.

[9] Tabet Helal et MA, Ghellai N. Le Gisement Eolien à Beni-Saf Région Côtière de l'Ouest Algérien. Review of Energy Ren: ICPWE 2003:143–6.

[10] Youcef Ettoumi F, Sauvageot et H, Adane. A-E-H. Statistical bivariate modelling of wind using first-order Markov chain and Weibull distribution. Renewable Energy 2003;28:1787–802.

[11] Kasbadji Merzouk N. Evaluation du gisement énergétique éolien contribution a la détermination du profil vertical de la vitesse du vent en Algérie. Thèse doctorat, Université Abou bekr Belkaid, Tlemcen; 2006.

[12] Chellali F, Khellaf A, Belouchrani A. Application of time–frequency representation in the study of the cyclical behavior of wind speed in Algeria: wavelet transform. Stochastic Environmental Research and Risk Assessment 2010;Vol8:1233–9.

[13] Chellali F, Khellaf A, Belouchrani A. Wavelet spectral analysis of the temperature and wind speed data at Adrar, Algeria. Renewable Energy 2010;35:1214–9.

[14] Carta JA, Ramirez P, Velazquez S. A review of wind speed probability distributions used in wind energy analysis. Cases studies in the Canary Islands. Renewable and Sustainable energy Reviews 2009;13:933–55.

[15] Burton T, Sharpe D, Jenkins N, Bossanyi E. Wind energy hand book. John Wiley and Sons; 2001.

[16] Peinke J, Schaumann P, Stephan Barth S. Wind energy. In: Proceedings of the Euromech colloquium. 2007.

[17] Mathew S. Wind energy, fundamentals. In: Resource analysis and economics. Berlin: Springer Verlag; 2006.

[18] Justus CG. Vent et performances des éoliennes. Edition SCM; 1980.

[19] Akpinar S, Akpinar EK. Wind energy analysis based on maximum entropy principle (MEP)-type distribution function. Energy Conversion and Management 2007;48:1140–9.

[20] Vender Hoven I. Power spectrum of horizontal wind in the frequency range from 0.0007 to 900 cycles per hour. Journal of Atmospheric Sciences 1956;14:160–4.

[21] Hwang HJ. Power density of surface wind speed on Palmyra Island. Monthly weather review. Monthly Weather Review 1970;98(Issue 1).

[22] Militello A, Kraus NC. Generation of harmonics by sea breeze in nontidal water bodies. Journal of Physical Oceanography 2001;31:1639–47.

[23] Shih.F D.C.-F. Wind characterization and potential assessment using spectral analysis. Stochastic Environmental Research and Risk Assessment 2008;22:247–56.

[24] Farge M. Wavelet transforms and their applications to turbulence. Annual Review of Fluid Mechanics 1992;24:395–457.

[25] Torrence C, Compo GP. A practical guide to wavelet analysis. Bulletin of the American Meteorological Society 1998;79:61–78.

[26] Madden AR, Julian PR. Observations of the 40–50-day tropical oscillation—a review. Monthly Weather Review 1994;122:814–37.

[27] Rehman S. Prospects of wind farm development in Saudi Arabia. Renewable Energy 2004;30:447–63.

[28] Juhari AB, Kamaruzzaman S, Yusoff A, Alghoul MA, Zaharim A, Ahmad I. Optimization of PV-wind-hydro-gasoline hybrid system by minimizing excess capacity. European Journal of Scientific Research 2009.

[29] Connolly D, Lund H, Mathiesen BV, Leahy M. A review of computer tools for analyzing the integration of renewable energy", into various energy systems. Applied Energy 2010;87:1059–82.